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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Navy Department

INVESTIGATION OF THE PRESSURE-LOSS CHARACTERISTICS

OF THE WESTINGHOUSE X24-C-2 INLET SCREEN

TED NO. NACA 0447

By

John L. Lankford

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

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[redacted]

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

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SUMMARY

At the request of the Bureau of Aeronautics, Navy Department, investigations of the static-pressure losses and total-head distributions of the Westinghouse X24-C-2 inlet screen were made in the induction aerodynamics laboratory at Langley. The screen was investigated in two configurations, both before and after rounding the leading edges of the vanes. Investigations were conducted through air flows up to about 80 pounds per second.

The results of the investigations indicate that pressure losses increase rapidly with increasing weight flow, and slight radial and circumferential variations are present downstream of the subject screen. The rounding of the vane leading edges reduced static pressure losses considerably and brought about slight improvements in total-pressure patterns.

INTRODUCTION

At the request of the Bureau of Aeronautics, Navy Department, investigations of the static-pressure losses and total-head distributions of the Westinghouse X24-C-2 inlet screen were made in the induction aerodynamics laboratory at Langley. The subject screen is designed for installation just upstream of the compressor blading in an annular turbojet inlet. The screen is proposed for ground tests of the unit to prevent particles of three-sixteenths of an inch diameter or greater from entering the compressor.

The performance of any turbojet propulsion unit is very adversely affected by losses or disturbances in the inlet flow.

A screen or grid, therefore, while beneficial in preventing foreign particles from entering the compressor blading, is usually undesirable from an aerodynamic standpoint. In order to develop a very satisfactory screen, it is necessary to evaluate its aerodynamic properties and its effect on inlet flow. The investigations have been conducted on the subject screen to determine the total-pressure patterns upstream and downstream and to measure the static-pressure losses across the screen. These investigations were conducted through the range of air flows in which the unit is designed to operate. Investigations were made on two configurations, first with the vane leading edges square and rough, and second, with the leading edges rounded.

SYMBOLS

H total pressure, pounds per square foot

p static pressure, pounds per square foot

Δp static pressure drop through screen, pounds per square foot

q dynamic pressure upstream of screen, pounds per square foot

W air flow, pounds per second

ρ density of air upstream of screen, slugs per cubic foot

ρ_o standard density, 0.002378 slugs per cubic foot

σ density ratio, ρ/ρ_o

Subscripts:

1 conditions at station 1

2 conditions at station 2

3 conditions at station 3

4 conditions at station 4

(All surveys measured clockwise from top center of ducting looking downstream)

a survey at circumferential position of 0°

b survey at circumferential position of 180°

c survey at circumferential position of 90°

d survey at circumferential position of 270°

i incompressible flow

DESCRIPTION OF APPARATUS

Inlet Screen

The inlet screen which appears in figure 1 is an all metal screen designed for installation in the annular turbojet intake opening. The screen is constructed of 31 circular vanes roughly thirty-thousandths of an inch in thickness and about five-sixteenths of an inch in depth in the direction of flow. These vanes are supported between boundary strips by 12 radial struts. The struts are V-shaped in the plane of flow, giving the assembled screen a staggered or double-conical form with the vane at the apex of the cone upstream and forming a circle which bisects the annular space. Details of the screen construction are shown in figure 2. The screen as received with the leading edges of the vanes square and rough is designated as configuration I. The leading edges of the vanes were rounded by hand after the results were obtained from the investigation of configuration I, and after rounding was designated as configuration II.

Screen Assembly and Other Apparatus

The screen was mounted in circular ducting of 21 inches internal diameter. The outer circumference of the screen was held by a wooden adapter ring and the inner screen boundary contained a wooden mock-up of the jet unit starter motor housing. The housing and the duct wall formed an annular measuring section which extended as a straight annulus through all measuring stations. Aft of the last station a tapered afterbody expanded the annulus to duct area again. A photograph of the screen, motor housing, afterbody, adapter ring assembly is shown in figure 1, and a photograph of the duct exterior is shown in figure 3. Power was supplied by a centrifugal blower to induce air from the laboratory through large bell inlets into cylindrical ducting. The ducting carried the air through the measuring section annulus of 2.123 square feet area, and finally diffused it for entrance into the blower inlet. A diagram of measuring station location and details is given in figure 4.

Instrumentation

All pressures were indicated on a multiple tube vertical manometer board connected to pressure tubes in the measuring section. Provisions were made for pressure surveys at all stations in the measuring annulus. A total pressure tube was located exactly in the center of the motor housing nose. Static pressure orifices and survey openings were located as shown in the cross sections of the duct in figure 5. A shielded thermocouple installed at station 1, gave stagnation temperature readings.

Preliminary pressure surveys indicated uniform static pressure distributions across the annulus both upstream and downstream of the screen. In the light of this information static orifices were used for static pressure determinations in the actual investigations Total-pressure distributions downstream of the screen were not very uniform, however, and surveys were used for total-pressure determinations in preference to the use of fixed multiple tube rakes. A photograph of one of the micrometer survey tubes is shown in figure 6. The micrometer feed on this survey tube permits positioning of the tube within one-thousandth of an inch along the survey radius.

METHODS OF PERFORMING TESTS

Flow Calibration

The approach section was calibrated as a nozzle for flow measurements, using average readings of the wall static pressures at station 3 and the total-pressure readings of the reference tube at station 2. A calibration curve is shown for this nozzle in figure 7. For convenience, a curve of Mach numbers at station 3 plotted against corrected weight flow is also given in figure 7.

Total-Pressure Surveys

Total-pressure surveys were made at stations 3 and 4. Surveys at station 4 were made along 4 radii spaced 90° apart circumferentially. The top of the ducting was taken as 0° and degrees were measured clockwise looking downstream. Surveys were not made directly downstream of screen struts. It was attempted to make all survey radii bisect the angle between screen struts as closely as possible.

Total-pressure surveys at station 3 indicated uniform pressure distribution upstream of the screen. Surveys at station 4 were made along 2 radii simultaneously. The tubes were then rotated to positions 90° removed from the first ones and the surveys were run in the new positions. As a result of this arrangement, since surveys required appreciable time, slightly different air flows and barometric pressures were occasionally encountered at each set of positions. The barometric pressure and weight flow have been shown or listed for each survey profile. On the manometer board all surveys were referenced to the tube in the nose of the motor housing. Tube readings were taken relative to the nose tube as a datum. Comparison of the reference tube with the tubes vented to atmosphere, showed them to be equal.

Static-Pressure Losses

Pressure losses were found by measuring the static pressure changes across the screen. Pressures were taken from individual tubes leading to static orifices of stations 3, 4, and 5. Differences were found by comparing individual tube readings with the references and each other.

Calculations on pressure losses in smooth ducting indicate that that magnitude of the pressure losses caused by the duct between stations 3 and 4 is smaller than the accuracy of measurements in this investigation. This is substantiated by the fact that no measurable loss is indicated between stations 4 and 5, which are located in ducting similar to that between stations 3 and 4. It is reasonable to assume, therefore, that all pressure losses measured are chargeable to the screen.

Configuration II was tested for static pressure losses in the same manner as configuration I. Total-pressure surveys were also taken at the 90° position for comparison with those of configuration I.

RESULTS AND DISCUSSION

Static Pressure-Loss Coefficient

The relation of static pressure-loss coefficient $\Delta p/q_1$ to weight flow W is shown for both configurations in figure 8. This coefficient was chosen in preference to the one based on loss of total pressure because of the greater convenience and accuracy with which it could be determined. This usage is conservative from the designers' standpoint because the static pressure drop coefficient is always equal to or larger than the total pressure drop coefficient. The difference in the coefficient will be greatest at maximum air flows and has been found by calculation to be of the order of 20 percent for configuration II tests at an air flow of 70 pounds per second.

The coefficient for configuration I is fairly constant at a value of 0.15 up to weight flows above 33 pounds per second. Above this air flow the coefficient rises until at a flow of 60 pounds per second a coefficient of 0.183 is indicated. The maximum value for configuration I in this investigation was 0.325 at a flow of 82.5 pounds per second. The second configuration shown also in figure 8 indicates that the screen after rounding exhibited lower pressure-loss coefficients for all flows. For the rounded-vane configuration a constant value of 0.105 was indicated up to a flow of about 45 pounds per second; this curve started to rise later than configuration I. At an air flow at 60 pounds per second the loss coefficient is 0.123 and reaches a maximum of 0.325 for this investigation at an air flow of 85.5 pounds per second.

Corrected Static-Pressure Loss

Absolute static pressure-losses corrected to standard conditions are shown in figure 9. The effect of rounding the vanes has been to decrease the losses as is shown by the position of the curves in the figure. At a weight flow of 60 pounds per second, which is approximately design flow, configuration I shows a loss of 30 pounds per square foot compared to the 20 pounds per square foot of configuration II. In short, at about design flow, rounding the vane leading edges has reduced losses by one-third. The curves rise sharply as air flows are increased until configuration I shows a loss of 95 pounds per square foot at 82 pounds per second and configuration II shows a loss of 106 pounds per square foot at a flow of 85.5 pounds per second.

Total-Pressure Distributions

Figure 10 shows the total-pressure distributions upstream of the screen at a weight flow of 28.24 pounds per second. Figures 11 and 12 show the upstream distributions at flows of 56.81 and 82.15 pounds per second, respectively. These patterns are very uniform and consistent over the range of proposed air flows. Only at a flow of 82.15 pounds per second, which is above design flow, does any loss in total pressure become apparent. At 82.15 pounds per second the loss is only about 0.1 percent of the total pressure available. The barometric pressure is shown on each sheet.

The total-pressure distributions downstream of the screen are shown in figures 13 and 14. Distributions are shown for

4 circumferential positions for configuration I and for 1 position for configuration II. Weight flows and barometric pressure lines are indicated on each graph. Variations both radially and circumferentially are present. Circumferential variations seemed greatest in an annular band slightly smaller in diameter than the center of the annular space between the motor housing and the duct wall. The maximum circumferential variation at design conditions is shown in figures 13(c) and 13(d) at 60 pounds per second air flow to be approximately 1.35 percent of the total available pressure. Maximum radial variation at a flow of 60 pounds per second is approximately 1.5 percent of the total upstream pressure. These figures are for configuration I. In general, the variations increase in magnitude with increasing air flow.

Configuration II for the air flows and positions tested showed the same general patterns, which were modified slightly by the rounded vanes. Figure 14 shows the total-pressure patterns at the 90° position for two air flows for configuration II.

Screen vanes are easily bent and deflected upon shipping and handling, this causes slight variations in downstream flow patterns.

The screen was tested for about 30 hours at flows above 70 pounds per second, for about 30 hours at moderate flows, and for about 20 hours at low flows.

CONCLUDING REMARKS

Investigations made to determine the static pressure losses and total-pressure characteristics of the Westinghouse X24-C-2 inlet screen indicate that, except at very low flow rates, losses increase and total-pressure variations become more pronounced with increasing weight flow. Smoothing and rounding the leading edges of the screen vanes slightly caused marked decreases in loss coefficients and improved total-pressure patterns slightly. Careful rounding and smoothing of all vanes as well as the leading edges of struts before assembly and removal of all lumps of solder and irregularities after assembly should reduce losses even more.

Individual screen vanes are subject to misalinement due to handling and storing of the assembled screen. This causes slight variations in flow patterns and total-pressure distributions. No structural failure was noted after 75 hours of testing.

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National Advisory Committee for Aeronautics
Langley Field, Va.

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1955

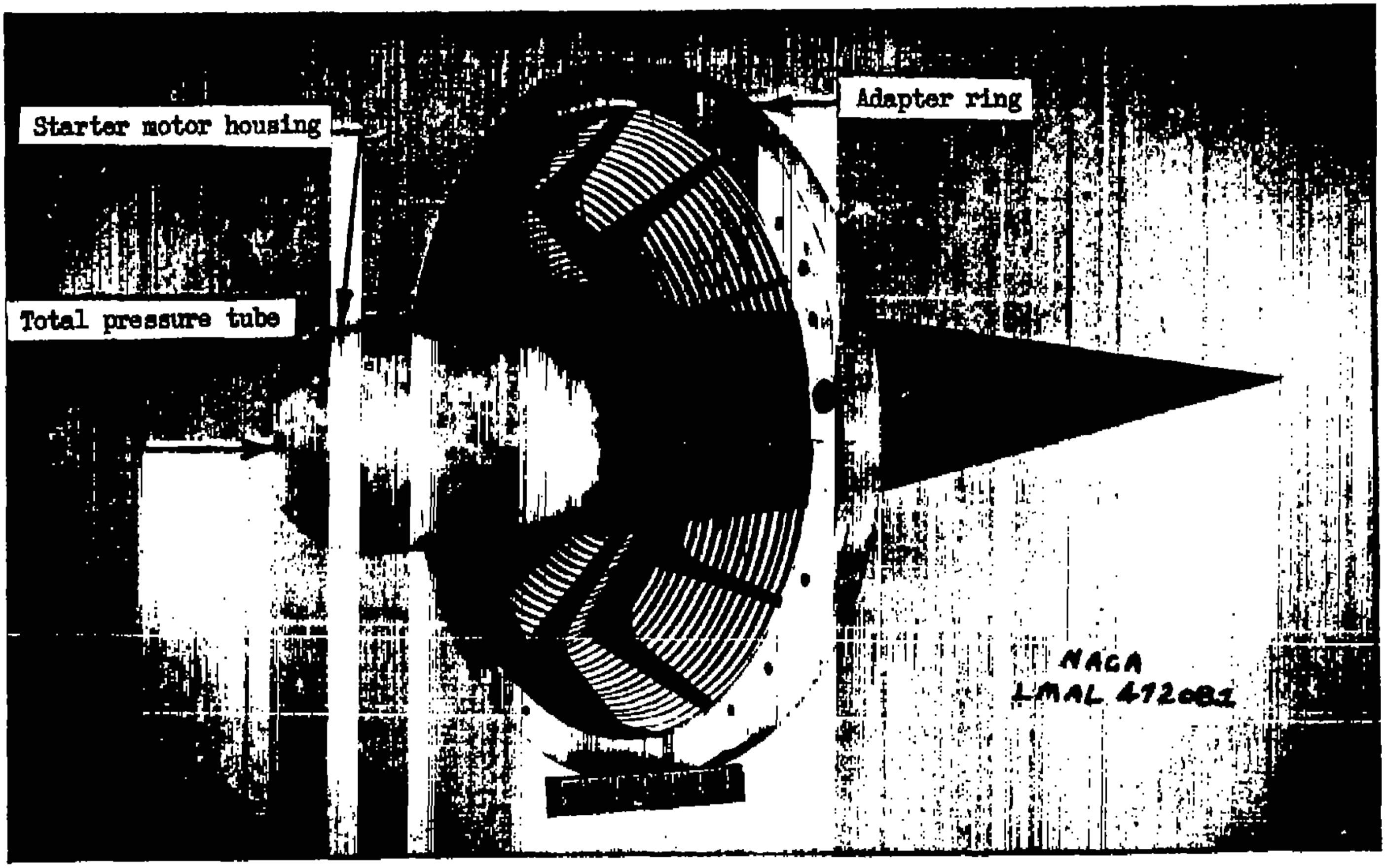

Figure 1.- Inlet grid and motor housing.

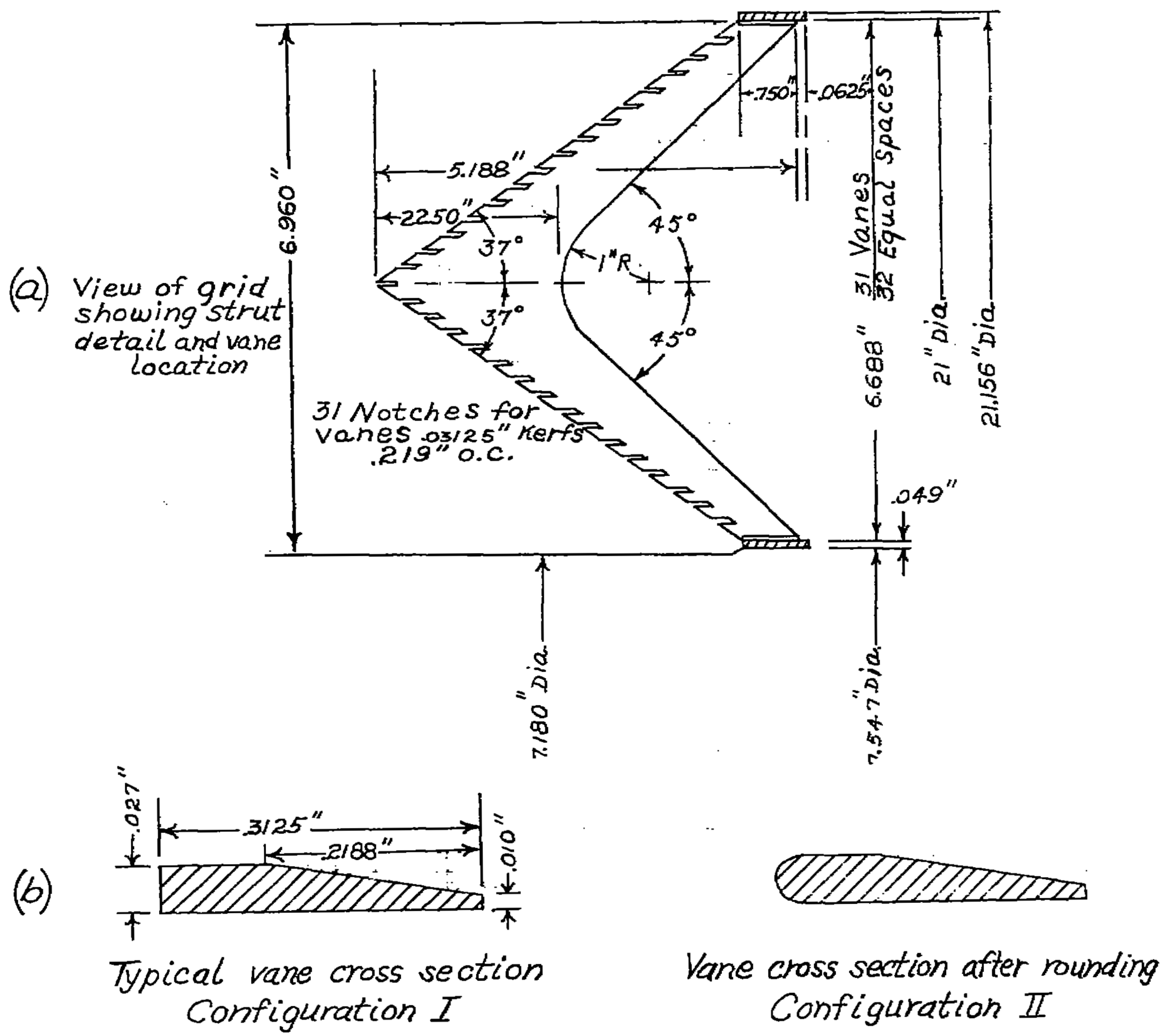

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Figure 2.- Details of grid struts and vanes.

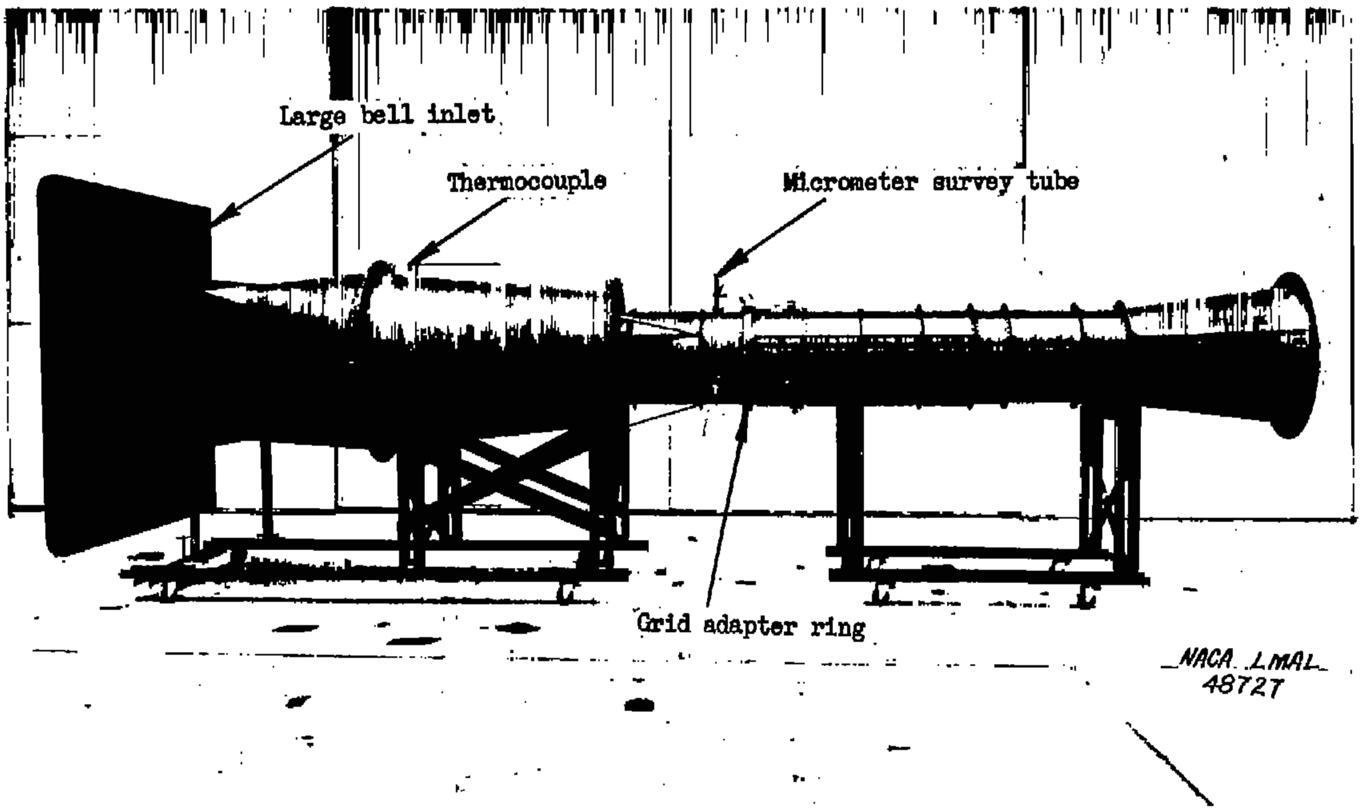

Figure 3.- General view of ducting and apparatus.

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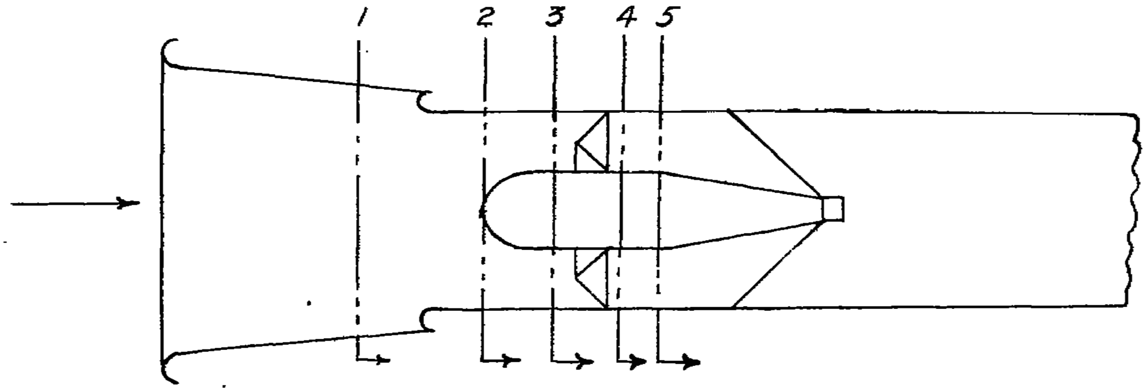
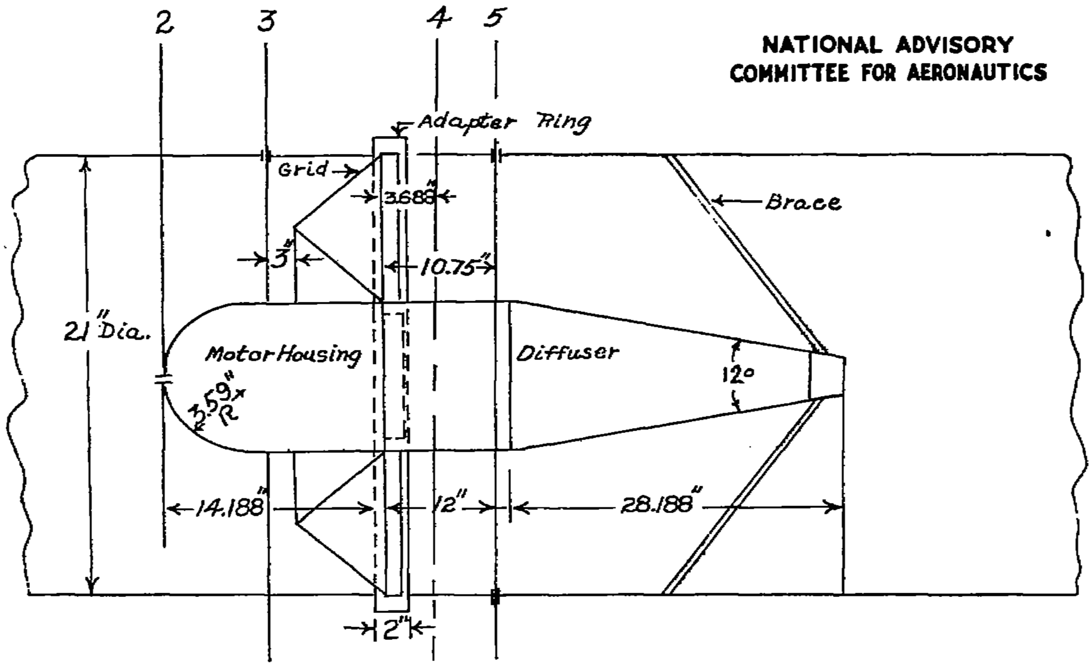


(a) Schematic view of all stations.



(b) Detail location of measuring stations.

Figure 4.- Location and details of measuring stations.

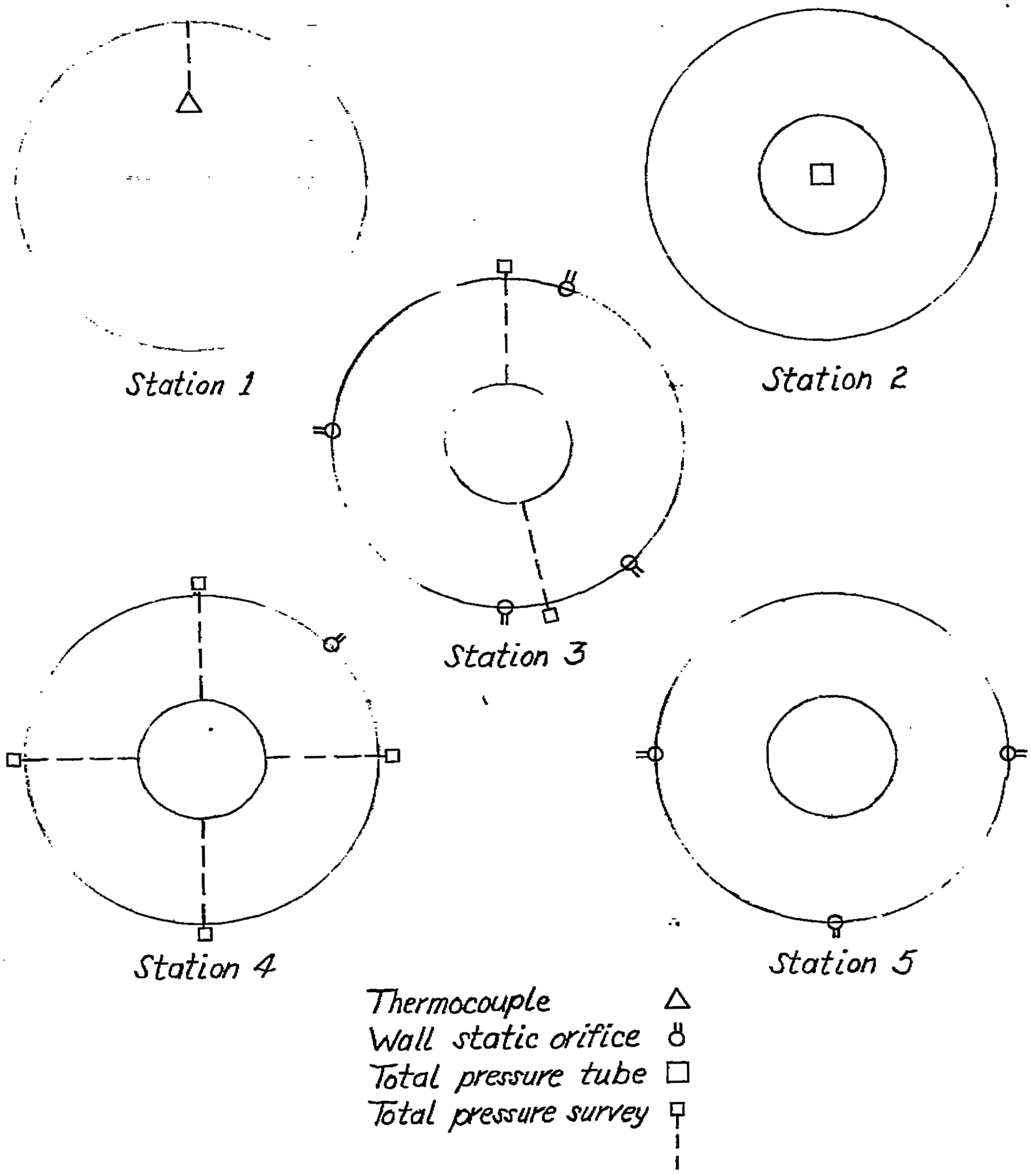


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Figure 5.- Sections through all stations showing instrumentation.

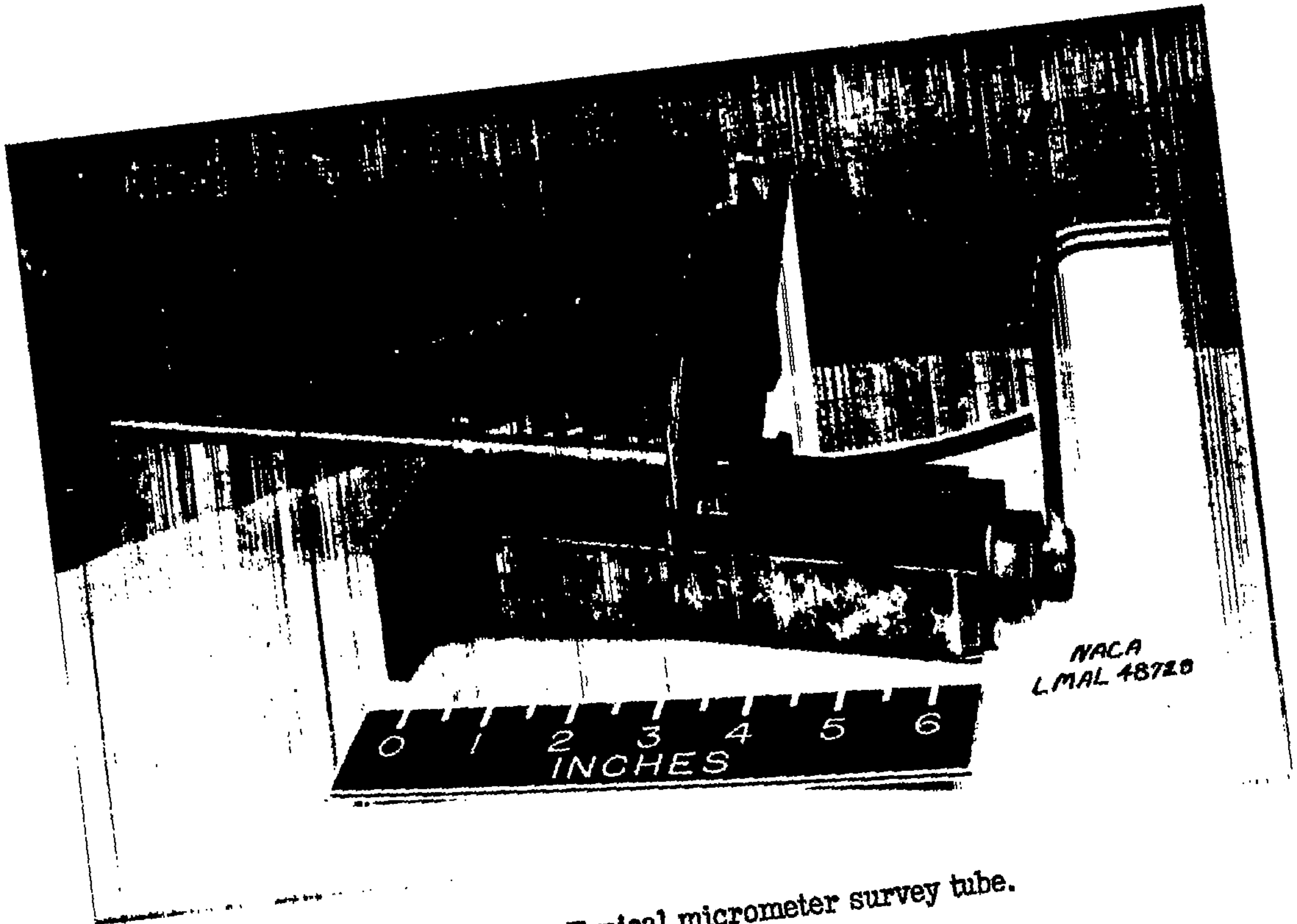


Figure 6.- Typical micrometer survey tube.

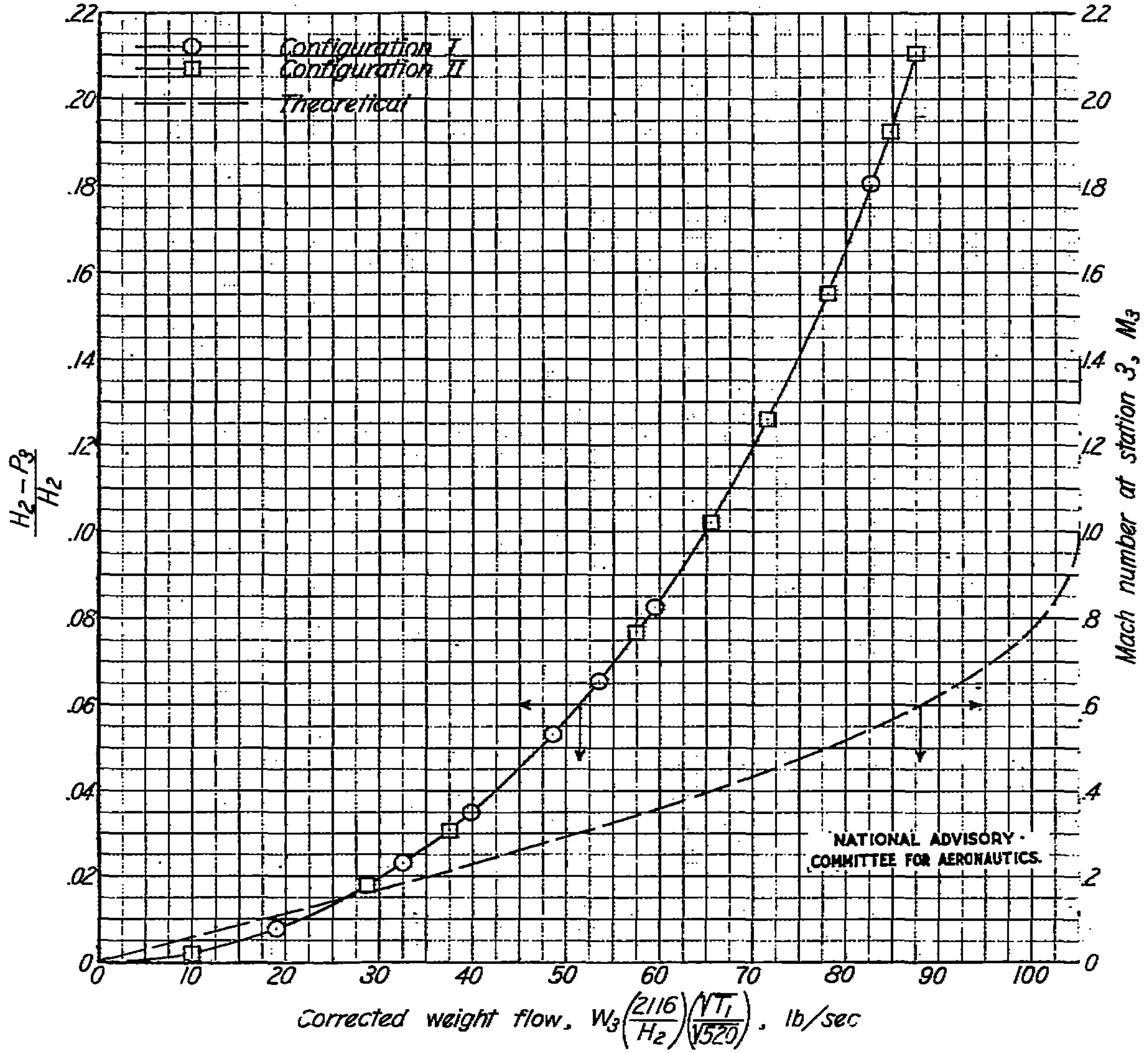


Figure 7.- Calibration curve for approach section and curve of theoretical Mach number, weight flow relations.

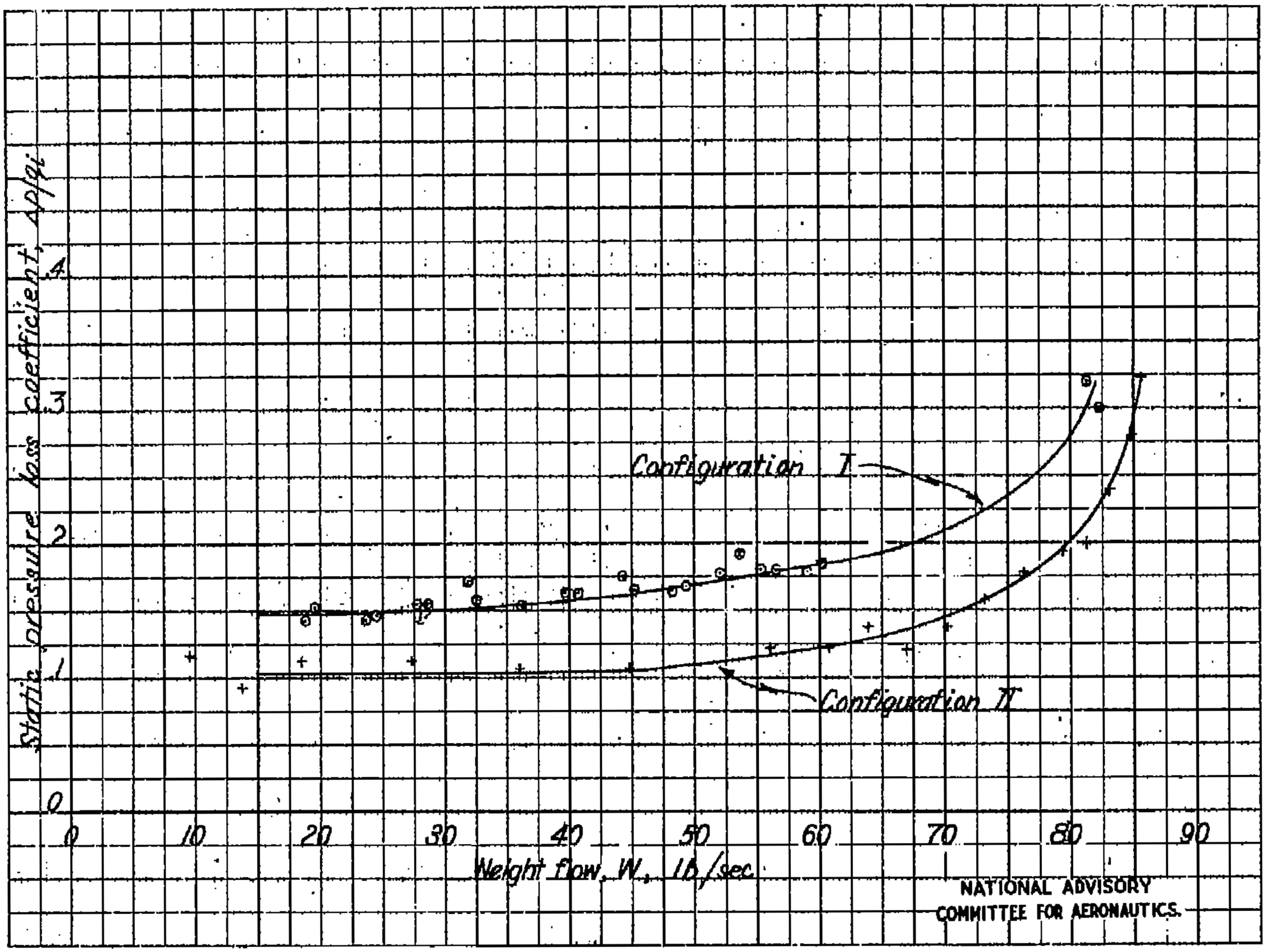


Figure 8.- Static pressure loss coefficient plotted against weight flow.

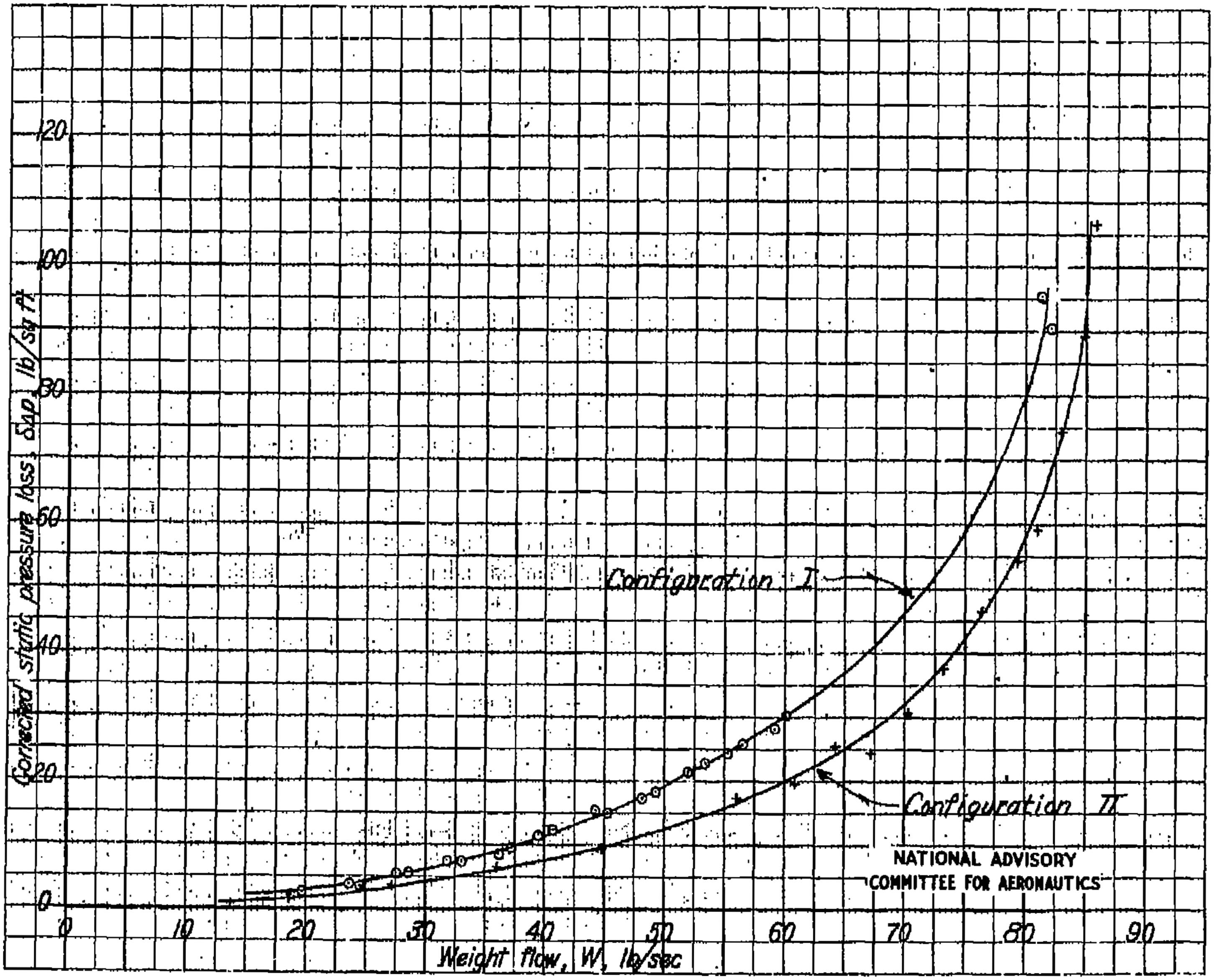


Figure 9.- Corrected static pressure loss plotted against weight flow.

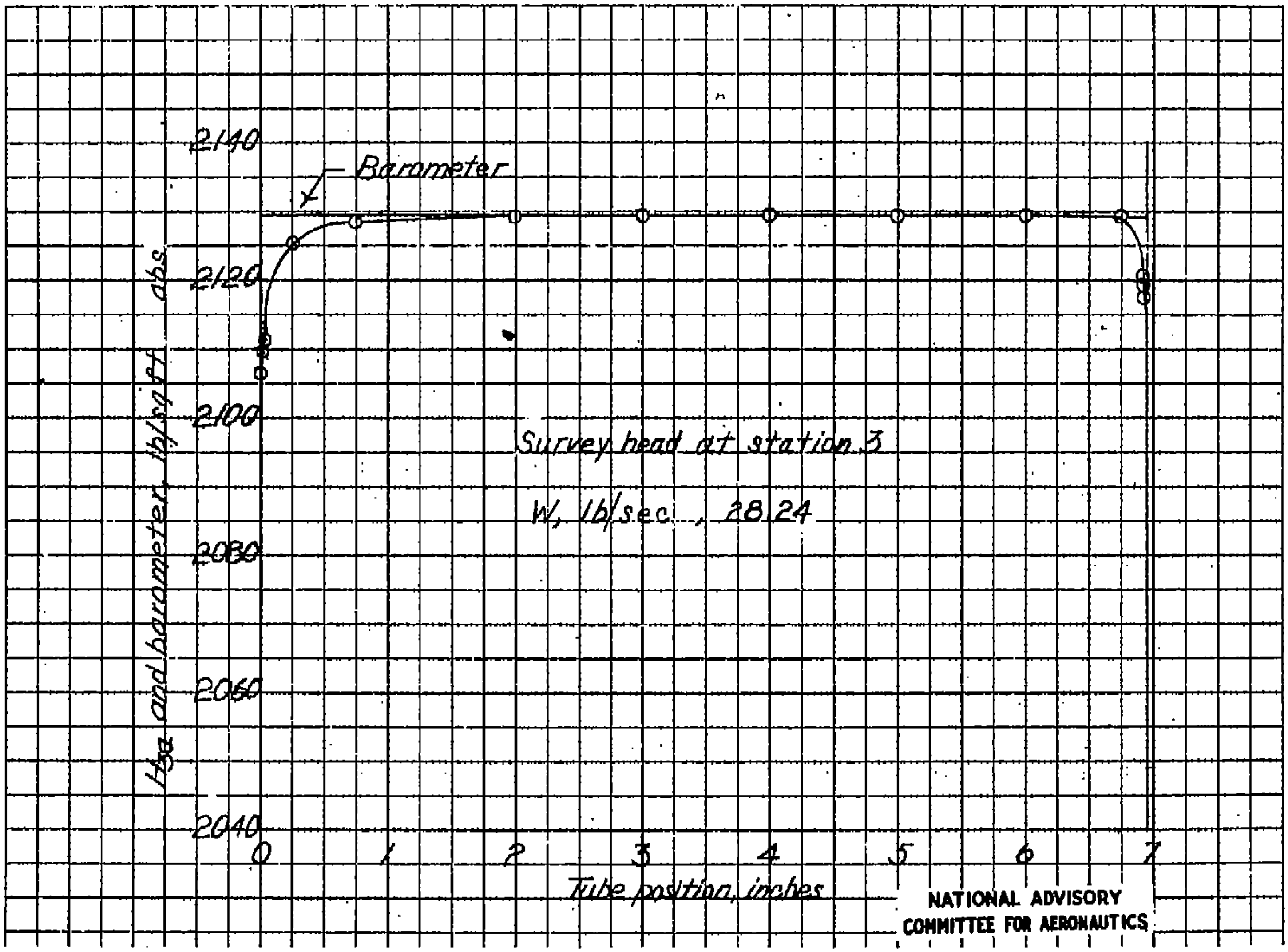


Figure 10.- Total pressure upstream of grid, weight flow 28.24 pounds per second.

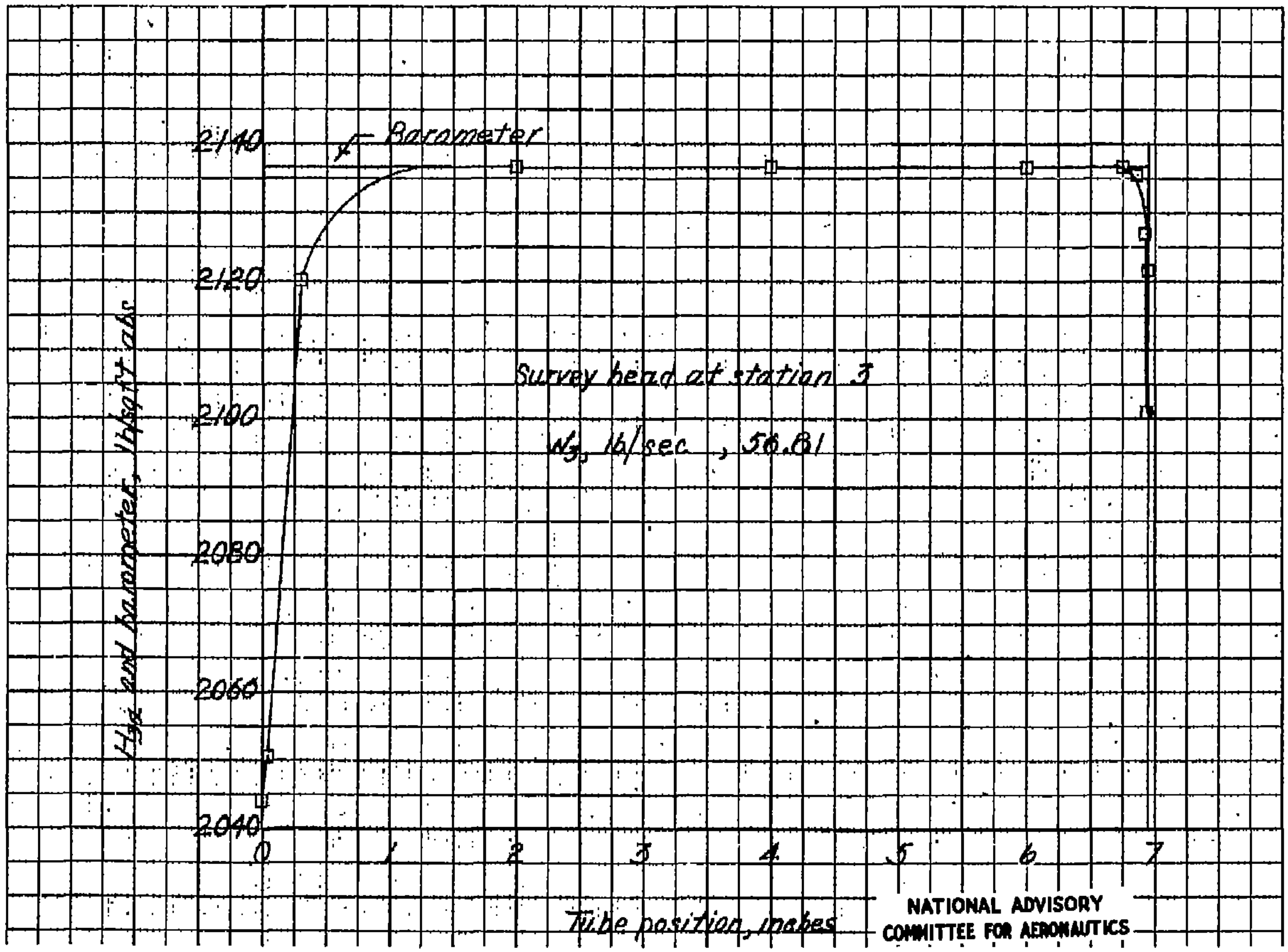


Figure 11.- Total pressure upstream of grid, weight flow 56.81 pounds per second.

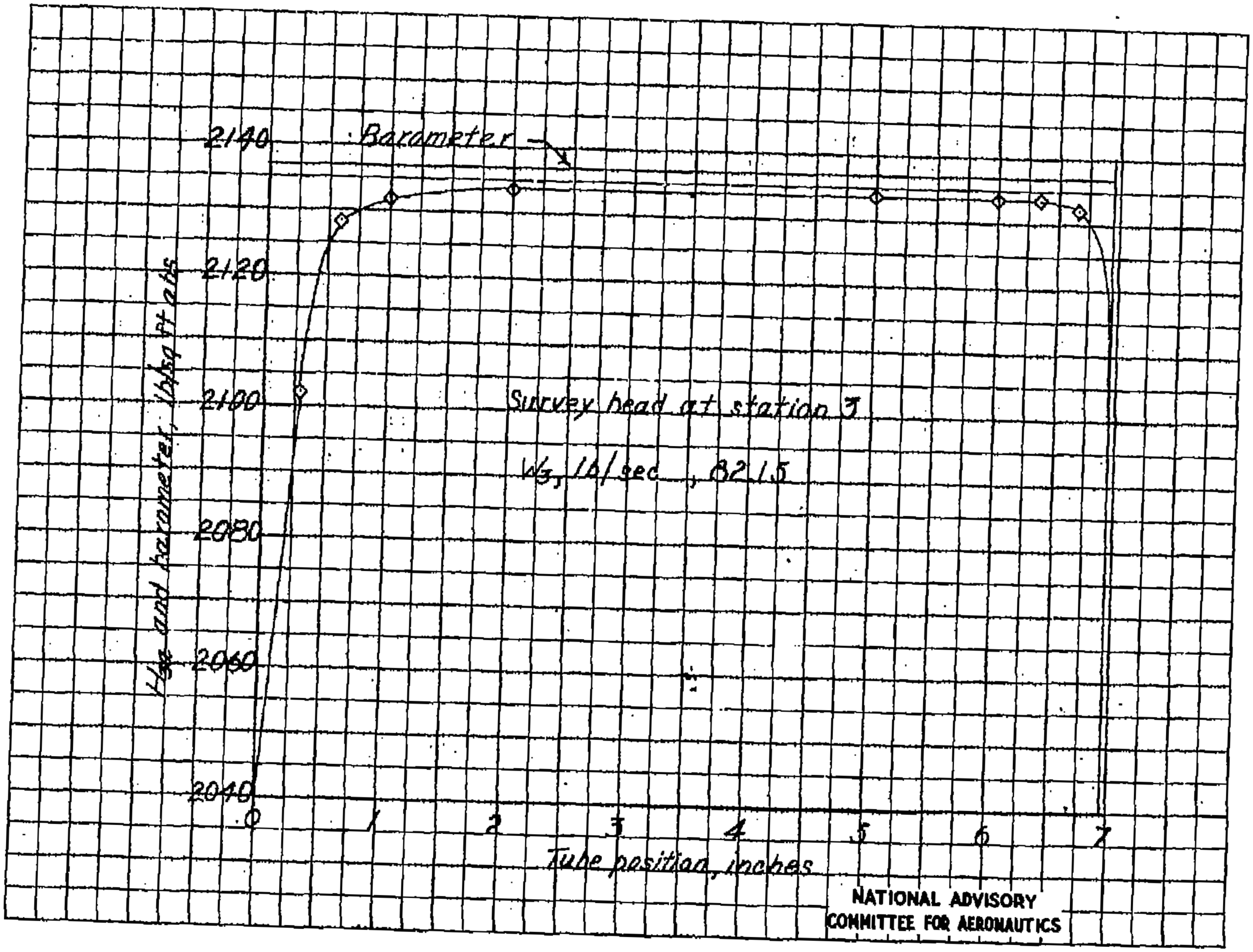
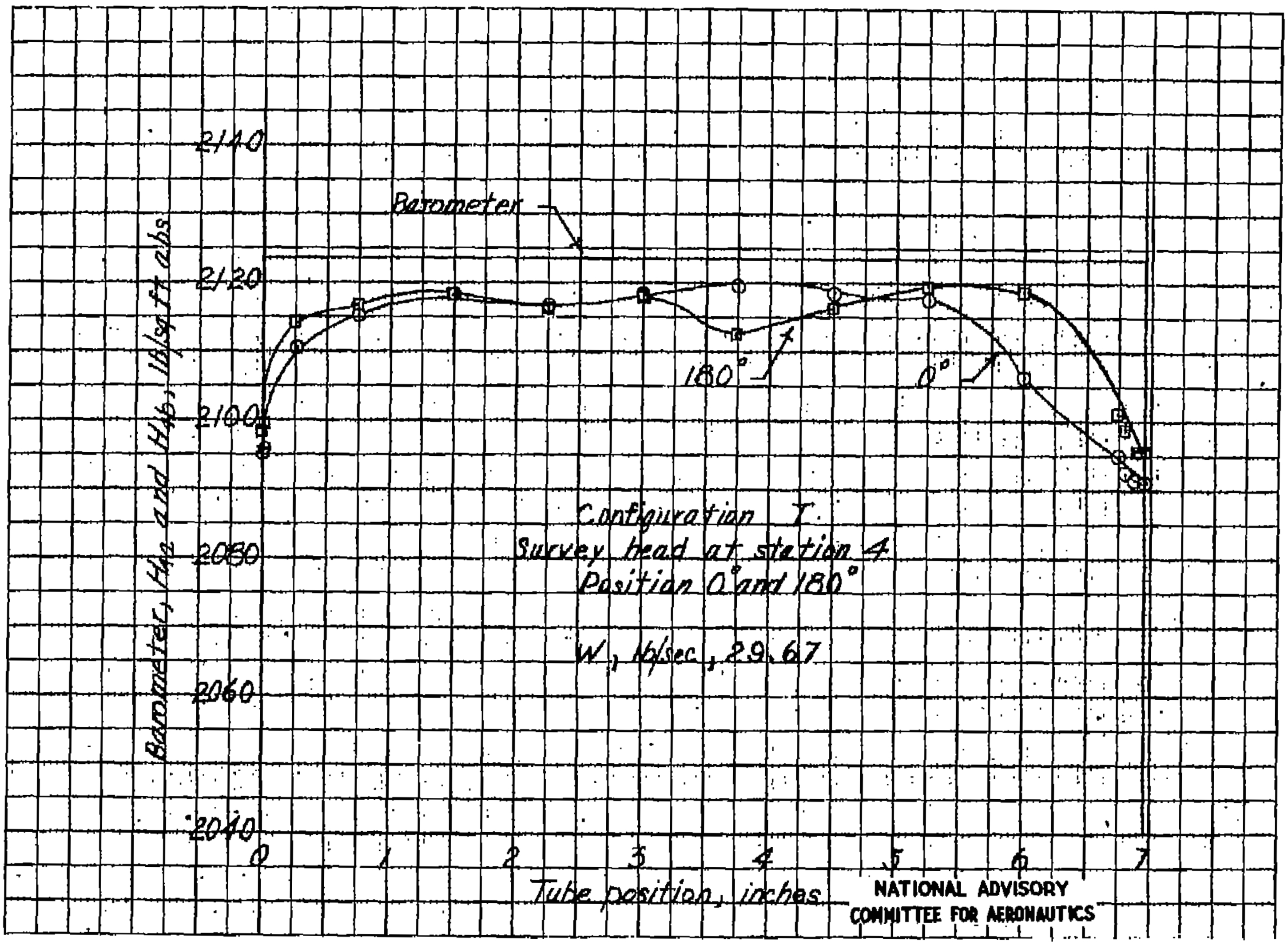
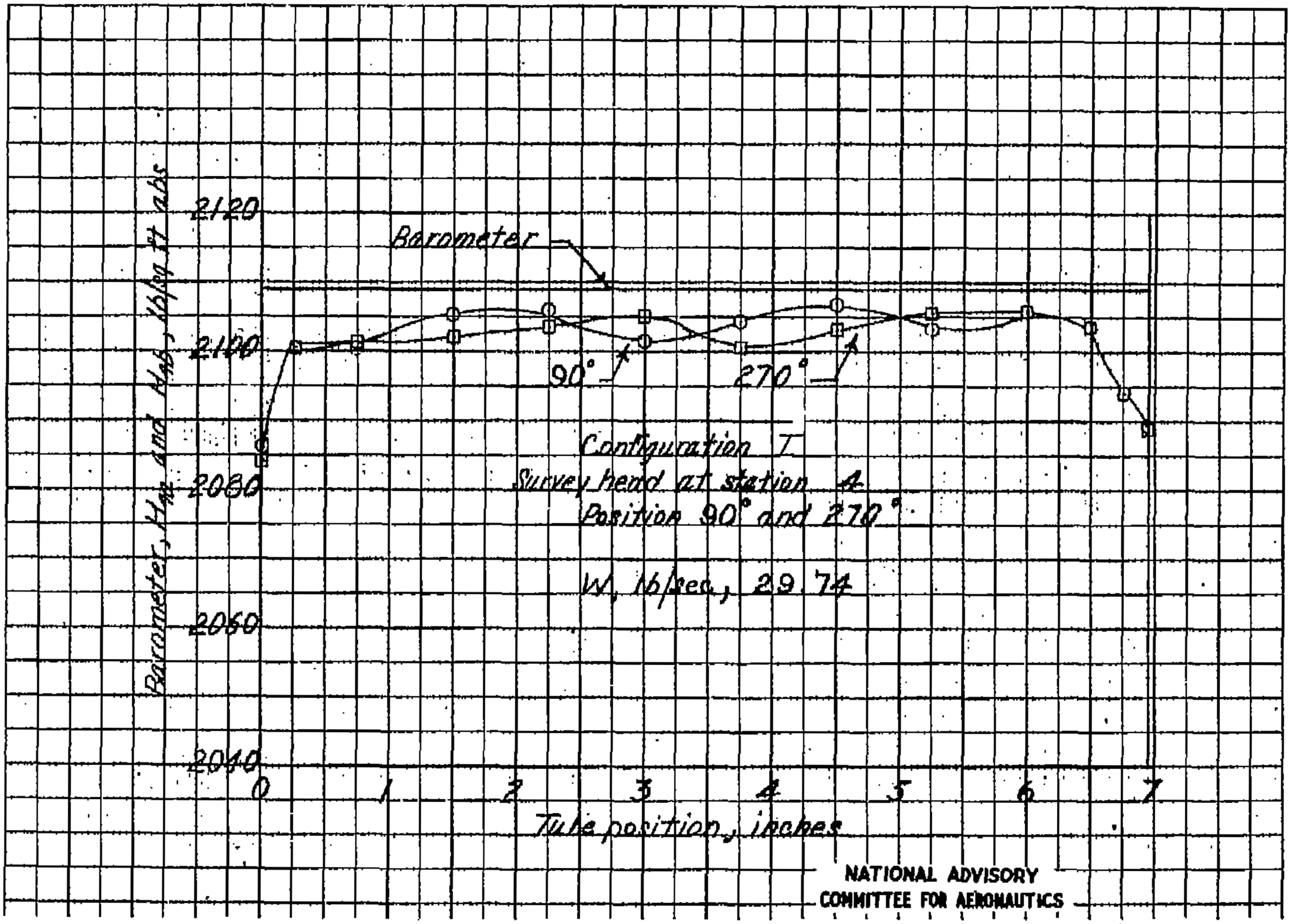


Figure 12.- Total pressure upstream of grid, weight flow 82.15 pounds per second.



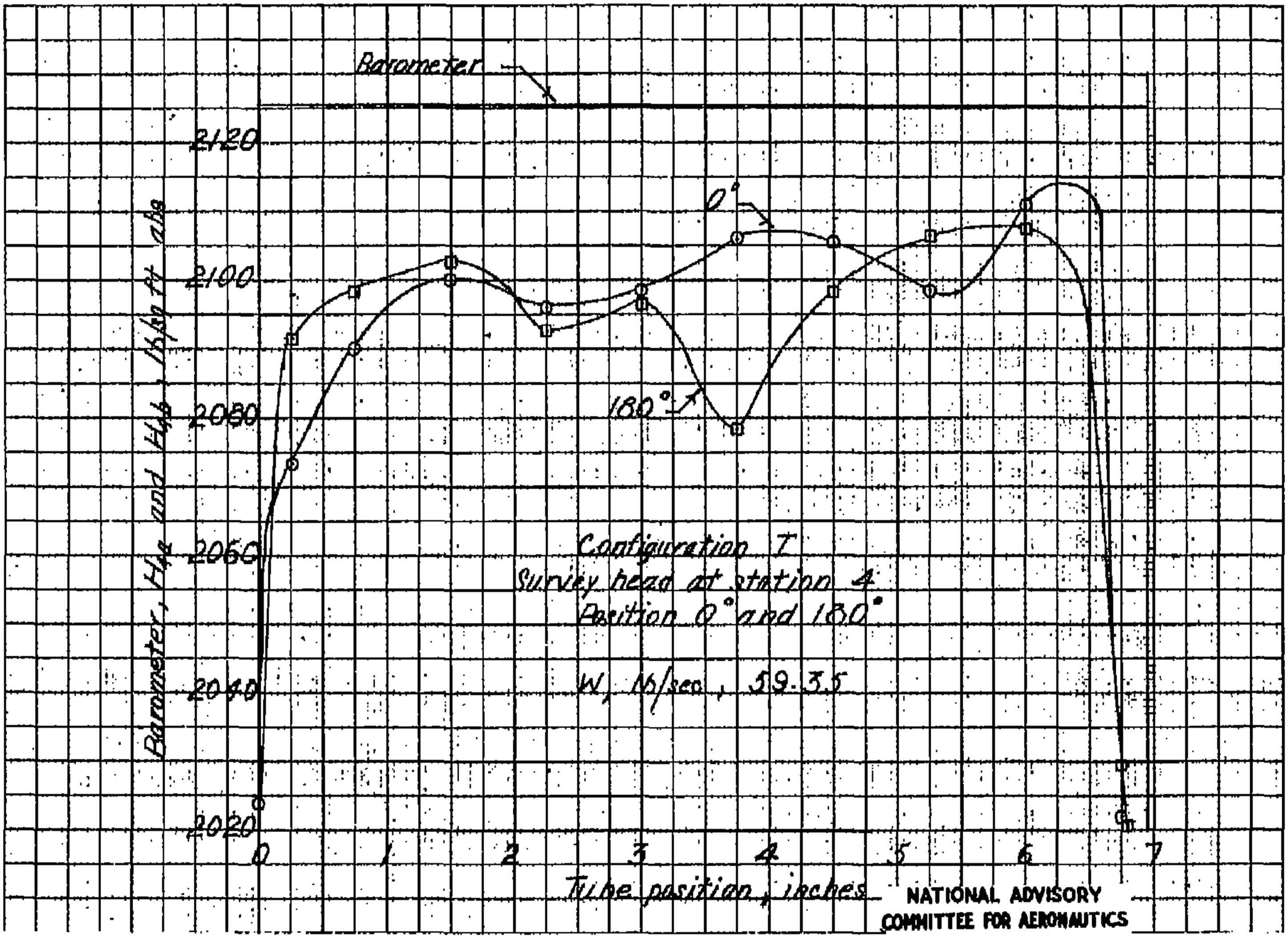
(a) Position 0° and 180°, flow 29.67 pounds per second.

Figure 13.- Total pressure downstream of grid, configuration I.



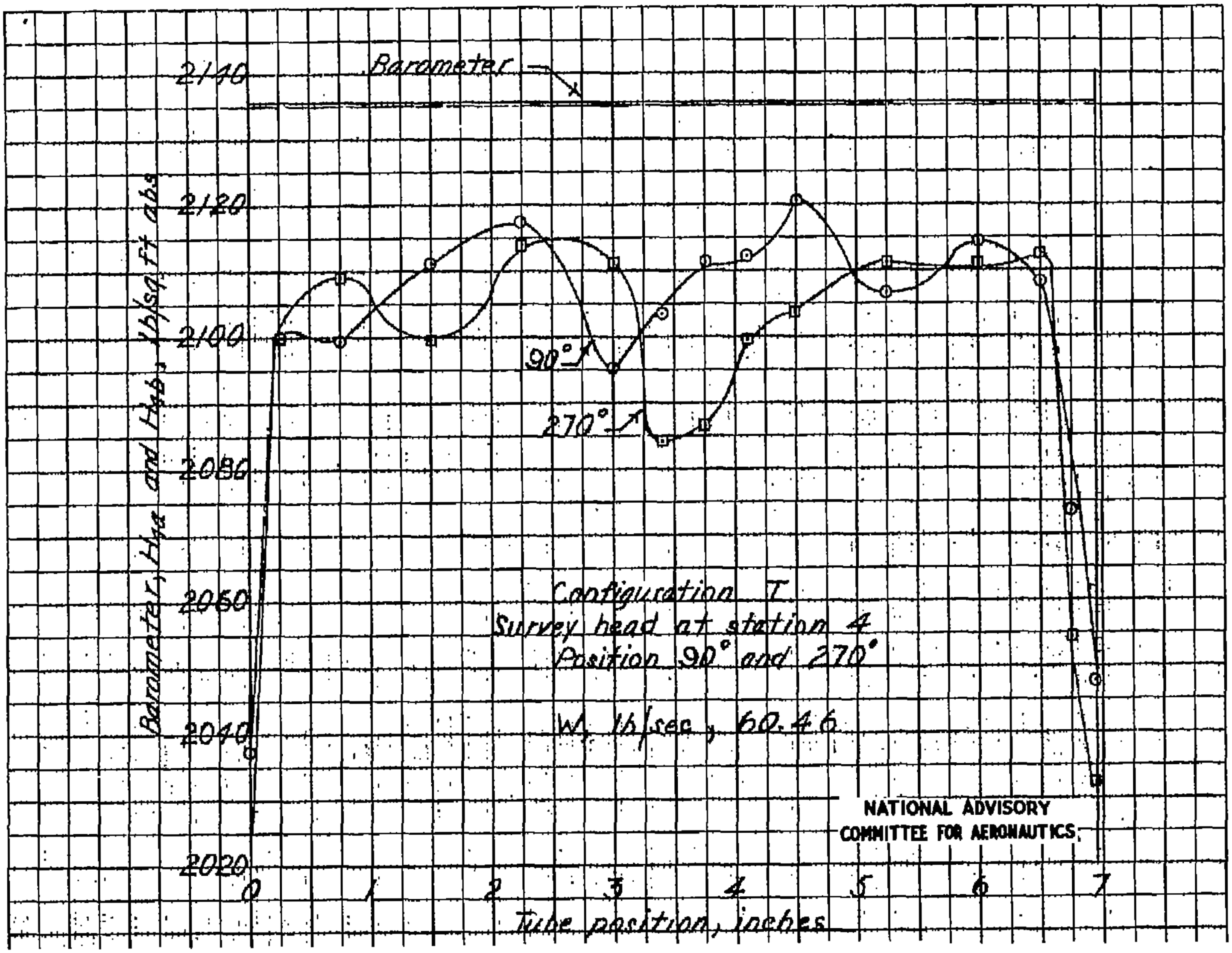
(b) Position 90° and 270°, flow 29.74 pounds per second.

Figure 13.- Continued.



(c) Position 0° and 180°, flow 59.35 pounds per second.

Figure 13.- Continued.



(d) Positions 90° and 270°, flow 60.46 pounds per second.

Figure 13.- Continued.

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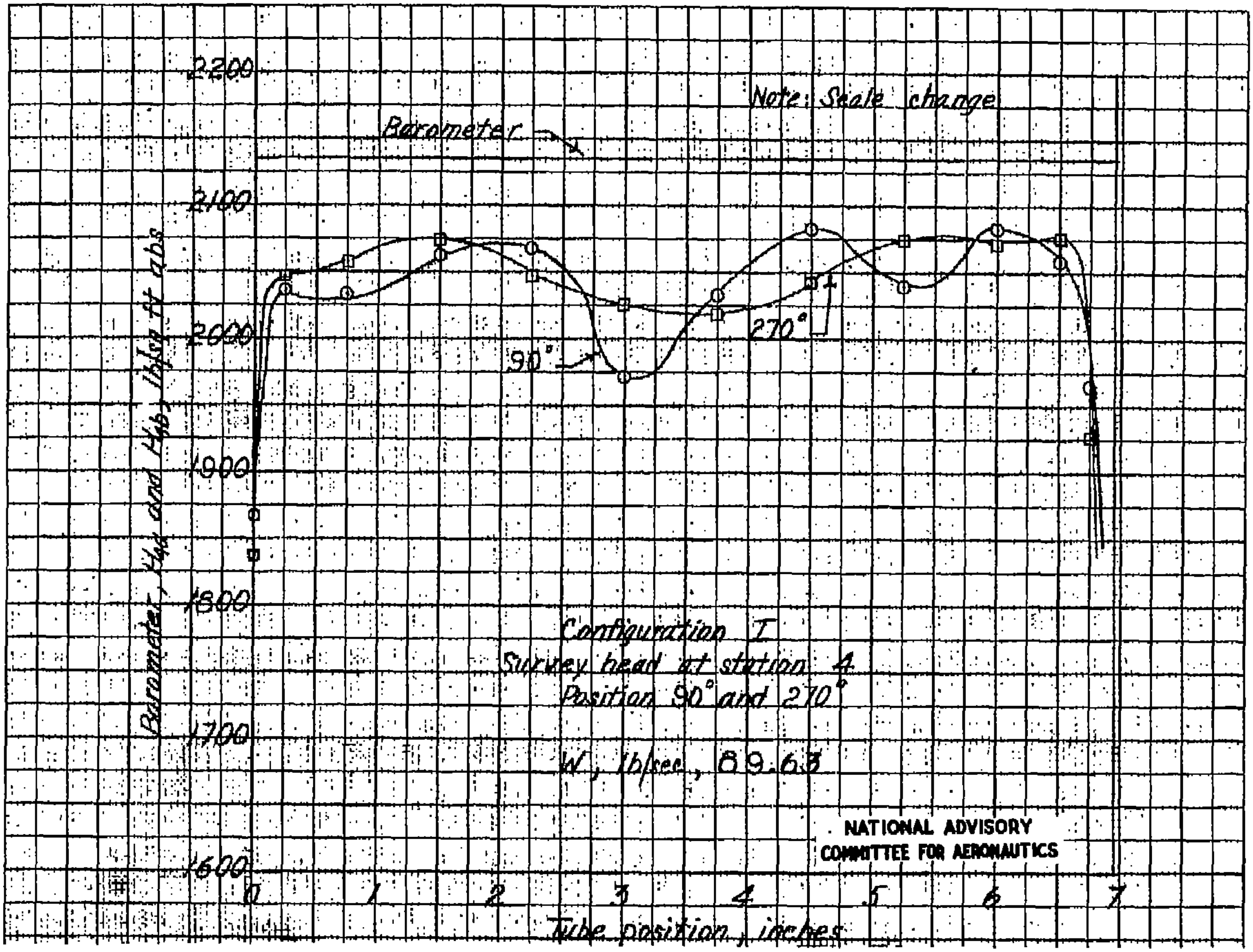
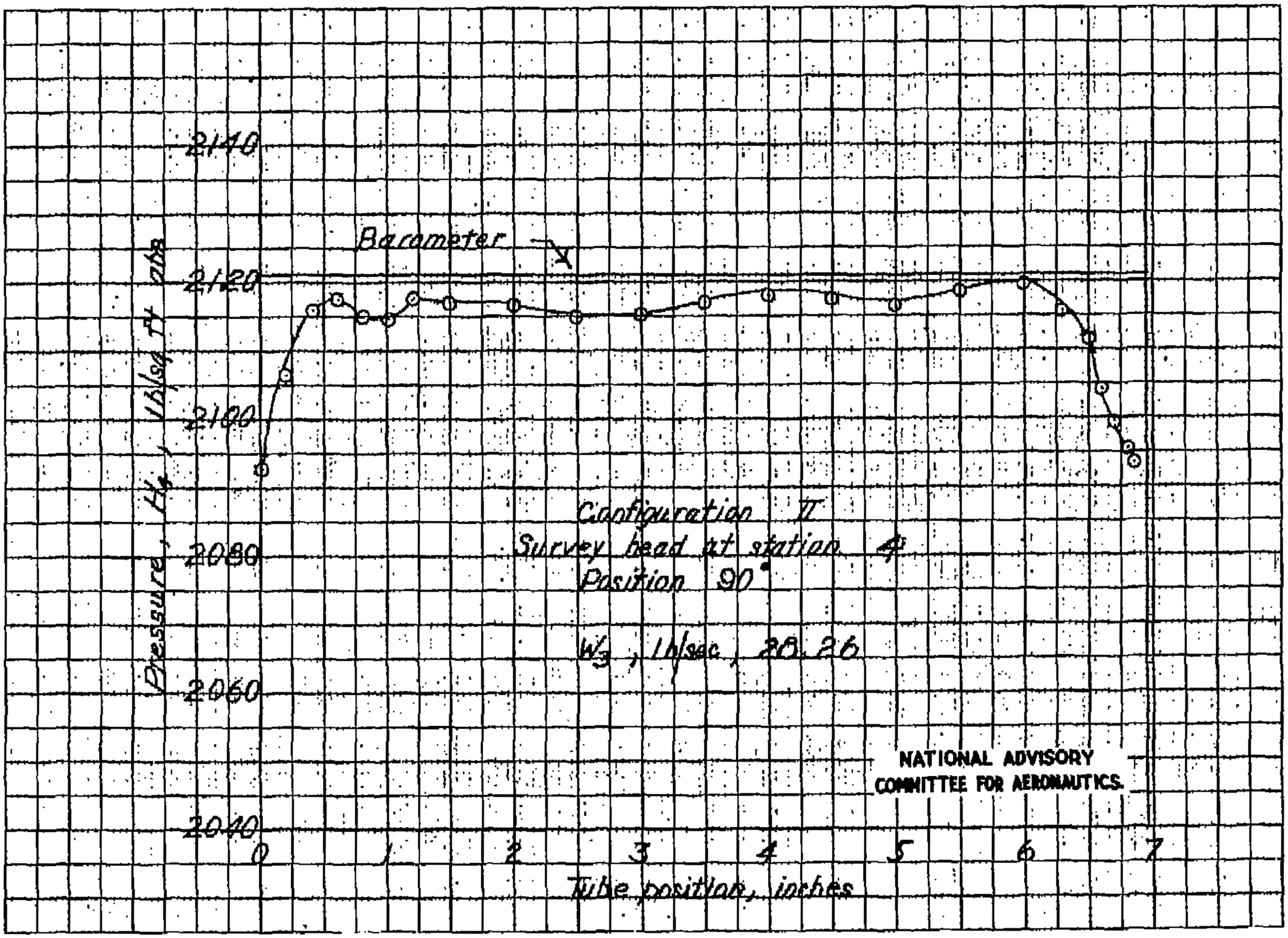


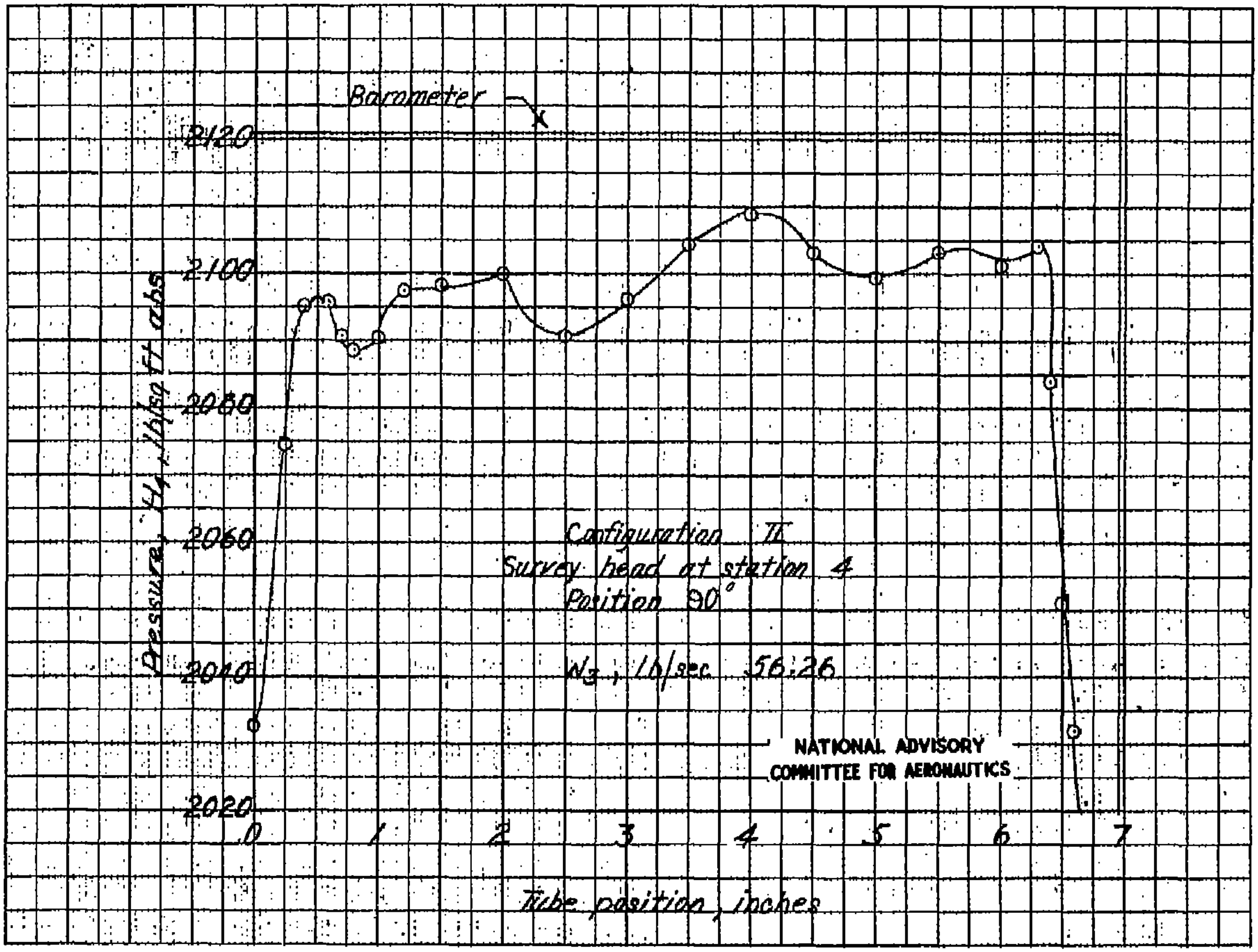
(e) Position 90° and 270°, flow 89.63 pounds per second.

Figure 13.- Concluded.



(a) Position 90°, flow 28.26 pounds per second.

Figure 14.- Total pressure downstream of grid, configuration II.



(b) Position 90°, flow 56.26 pounds per second.

Figure 14.- Concluded.

Ducts

Jet - Turbo